

## **Toward a Coupled Ocean-Wave-Atmosphere Model of Typhoon Impacts on the Western Pacific**

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### **LONG-TERM GOALS**

This work aims to understand the interaction between ocean, wave and atmosphere under typhoon condition. Applying the knowledge learned to improve Navy ocean prediction capability.

### **OBJECTIVES**

The first objective of this effort is to develop an ocean model to cover the Typhoon DRI study area at the West Pacific applying a Naval Research Laboratory (NRL) Ocean Nowcast/Forecast System (ONFS) (Ko et al., 2008). The second objective is to conduct real-time prediction applying the model to provide ocean conditions to support the field experiments. The third objective is to collaborate with other Typhoon DRI PIs as well as the PIs from related projects such as the Taiwanese ITOP (Interaction of Typhoon and Ocean Project) and TCS-08 (Tropical Cyclone Structure field experiment in the Western North Pacific) to study the impact of typhoon and wave on the ocean applying models and observations. The finally objective is to use observational data to evaluate the model responses to typhoon and apply the result to improve the operational applications.

### **APPROACH**

To achieve the objectives an ocean model that covers the Typhoon DRI experiment area in the Western North Pacific Ocean is developed based on the NCOM (Navy Coastal Ocean Model, Martin, 2000). NCOM has been applied for operation at NAVO in a global scale (Barron, 2004) and a relocatable regional scale. One of the Navy's operational wave models, SWAN, is utilized to provide surface wave condition for ocean-wave interaction study in collaboration with Typhoon DRI PI S.-Y. Chao of University of Maryland. Navy operational meteorology products from NOGAPS and COAMPS are used to provide the surface forcing for the ocean and wave models. By using Navy operational ocean and wave models and meteorological products to conduct Typhoon impact studies, the results can be more directly applied to improve Navy's ocean/wave/meteorology prediction capabilities.

Real-time ocean nowcast/forecast experiments are conducted applying the ocean model or the East Asian Seas Nowcast/Forecast System (EASNFS) with a realistic meteorology forcing from NOGAPS and COAMPS. Satellite altimeter data and MCSST are used for data assimilation to produce realistic

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ocean conditions. Figure 1 shows EASNFS 72-hour forecast for 2009/10/03 00Z. The real-time prediction and the derived products are useful for mission planning in support of field experiments such as TCS-08 (Tropical Cyclone Structure field experiment in the Western North Pacific) at summer of 2008 and Typhoon DRI field experiment at 2010. The ocean predictions are provided to other Typhoon DRI PIs for initialization and boundary conditions to ocean/wave/atmosphere models. The real-time prediction will be serving as the baseline to evaluate against the predictions from improved ocean model or forcing and wave coupling. The realistic ocean predictions are also useful, in place of real ocean, in a virtual field experiment to evaluate the experiment design.

We will collaborate fully with the researchers from Typhoon DRI, ITOP and TCS-08. Contribute the model results and perform model twin experiments, together with observations, to conduct studies related to typhoon. Subjects of interest are oceanic responses to typhoon and the influence of ocean on the typhoon intensity. We also plan to study the ocean-wave two-way interaction and investigate how the surface waves affect the ocean mixing under the typhoon, strong wind condition, and study the impact of typhoon induced strong current on the wave model prediction. We expect to obtain the data from field observations and apply the data to evaluate the ocean/wave model and Navy operational meteorology prediction used for the model forcing.

The knowledge learned are then applied to improve the ocean and wave model prediction for transition to operation.

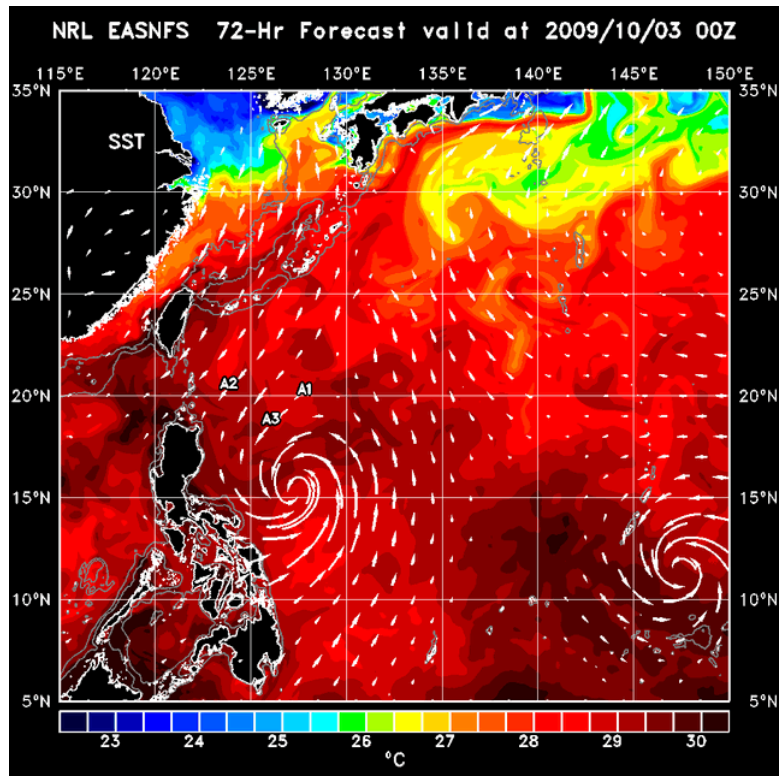
## **WORK COMPLETED**

Conducted real-time ocean prediction using NRL EASNFS on a daily basis. Provided the ocean prediction products, up to 72-hour forecast (Figure 1), the satellite remote sensing products (Figures 2 and 3), and weather forecast products from FNMOC (Figures 4 & 5) to support ONR Typhoon DRI virtual experiment for the typhoon-ocean interaction at the West Pacific Ocean. A website ([http://nrlssc7320.navy.mil/NLIWI\\_WWW/ITOP\\_WWW/ITOP.html](http://nrlssc7320.navy.mil/NLIWI_WWW/ITOP_WWW/ITOP.html)) was setup to provide the products. The ocean predictions are made available to Typhoon DRI PIs for download to be used for initialization and for boundary conditions for the models. The daily EASNFS ocean prediction products are also used to support other ONR field experiment (QPE) (Figure 6).

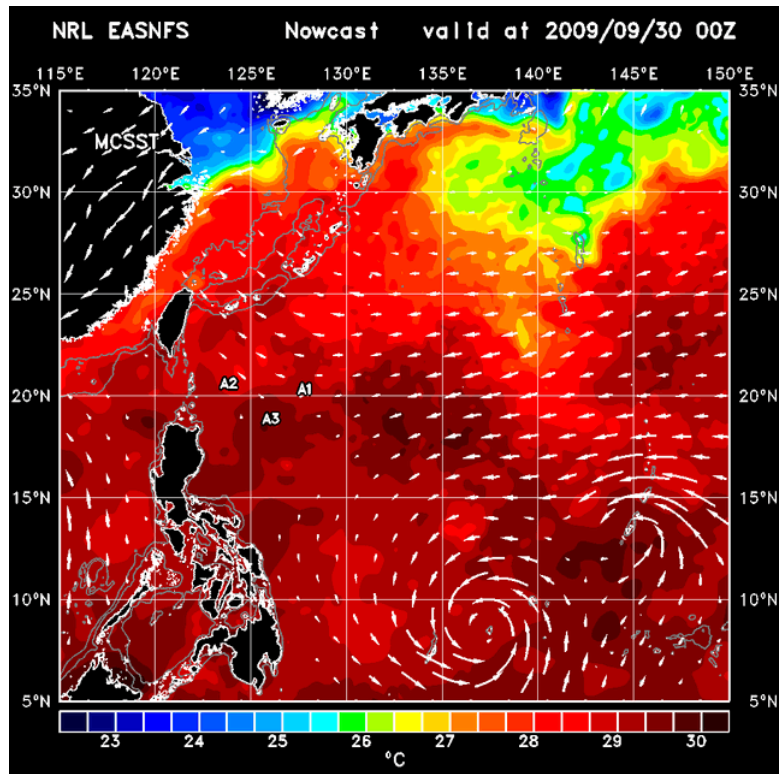
Requested by Typhoon DRI PIs we also operated a real-time ocean nowcast/forecast system which covers the Gulf of Mexico, the Caribbean Sea and part of North Atlantic Ocean to support the field experiment for hurricane-ocean interaction study at North Atlantic Ocean. This Intra-Americas Sea Ocean Nowcast/Forecast System (IASNFS, Ko et al., 2003) (Fig. 7), is operated daily during the 2009 hurricane season. IASNFS prediction is available to Typhoon DRI PIs over the website ([http://nrlssc7320.navy.mil/NLIWI\\_WWW/ITOP\\_WWW/ITOP.html](http://nrlssc7320.navy.mil/NLIWI_WWW/ITOP_WWW/ITOP.html))

In collaboration with ONR Typhoon DRI PI, S.-Y. Chao of University of Maryland to conduct research on the typhoon-wave-ocean interaction. Developed a high-resolution ocean nowcast/forecast system for the area around the Taiwan ITOP moorings and is coupled to the EASNFS. The system was tested and transitioned to University of Maryland for operation. Coached a graduate student, Y. T. Chang, to operate the system and conducted hindcast for 2007 typhoon season.

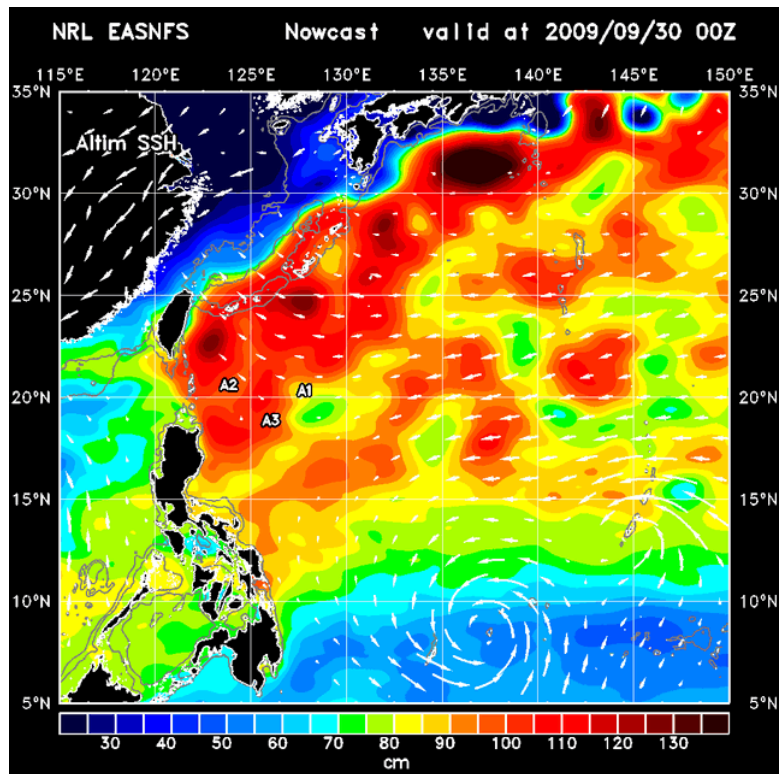
Collaborated with Chao et al., revised a paper in study of the impact of Typhoon Fenshen on the coastal environment (Ko et al., 2009). The paper was accepted for publication in the *Terrestrial, Atmospheric and Oceanic Sciences*.



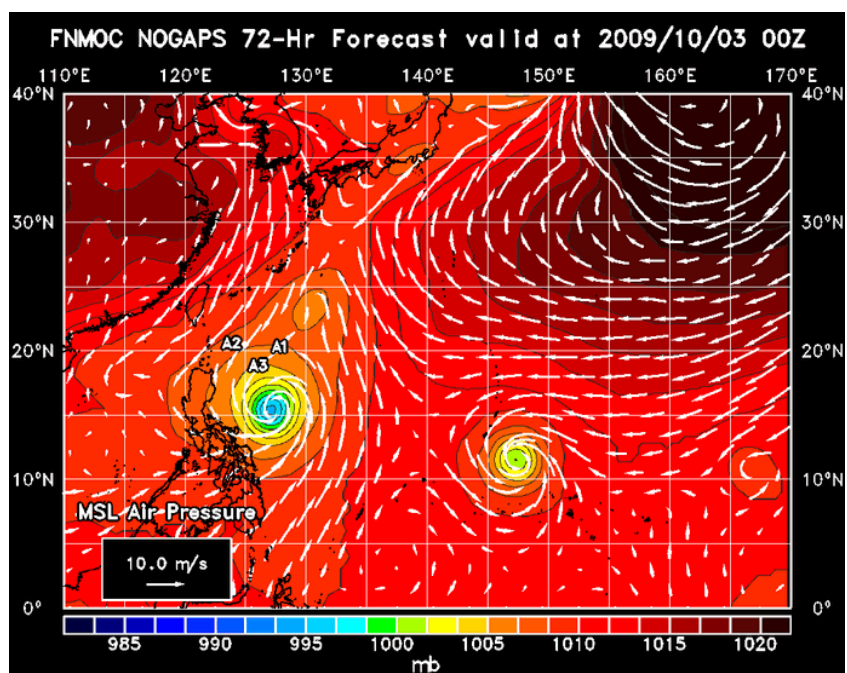
*Figure 1. The NRL EASNFS 72-hour forecast of sea surface temperature for 2009/10/03 00Z. The wind stresses from FNMOC NOGAPS showing Typhoon Parma and Tropic Storm Melor are superimposed. The mornings deployed by Taiwan ITOP are indicated by A1, A2 & A3.*



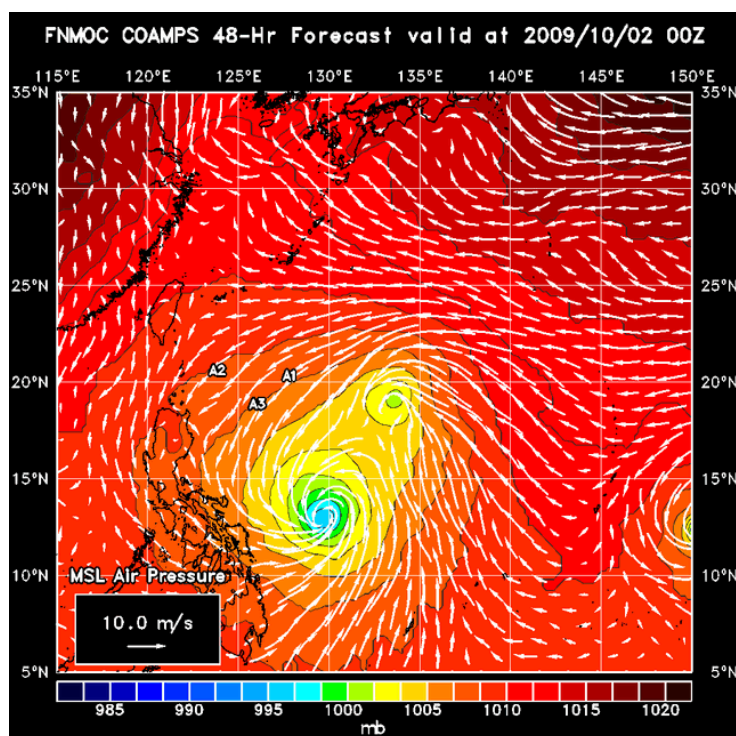
*Figure 2. Satellite Multi-Channel Sea Surface Temperature (MCSST) analysis for 2009/09/30 00Z.*



*Figure 3. Satellite altimeter sea surface height (ssh) composite for 2009/09/30 00Z. A 6-year average EASNFS ssh is used for mean ssh in the analysis.*

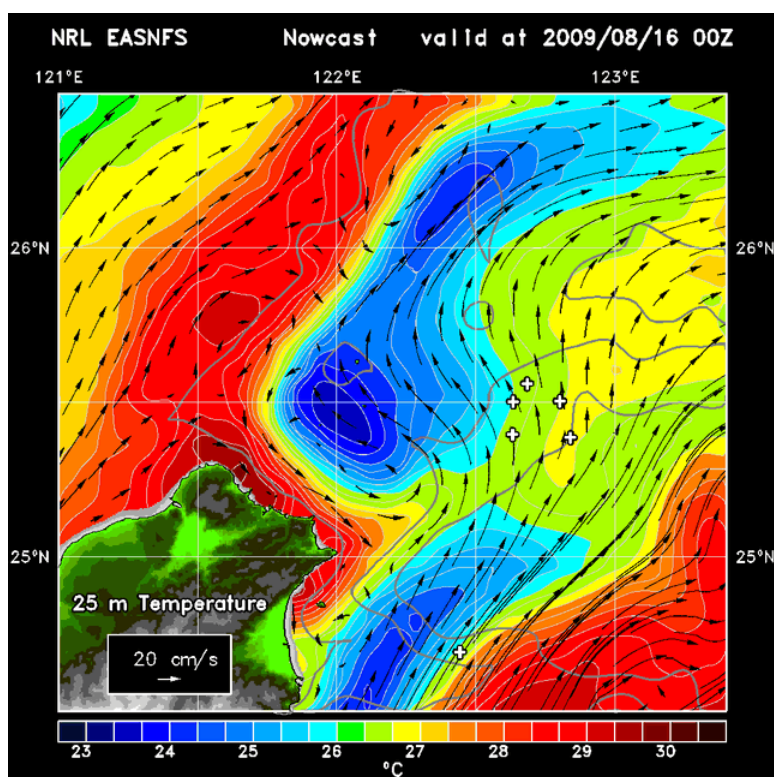


*Figure 4. FNMOC NOGAPS global weather forecast model 72-hour forecast for 2009/10/03 00Z. Colors show sea level air pressure with wind speed vector superimposed.*

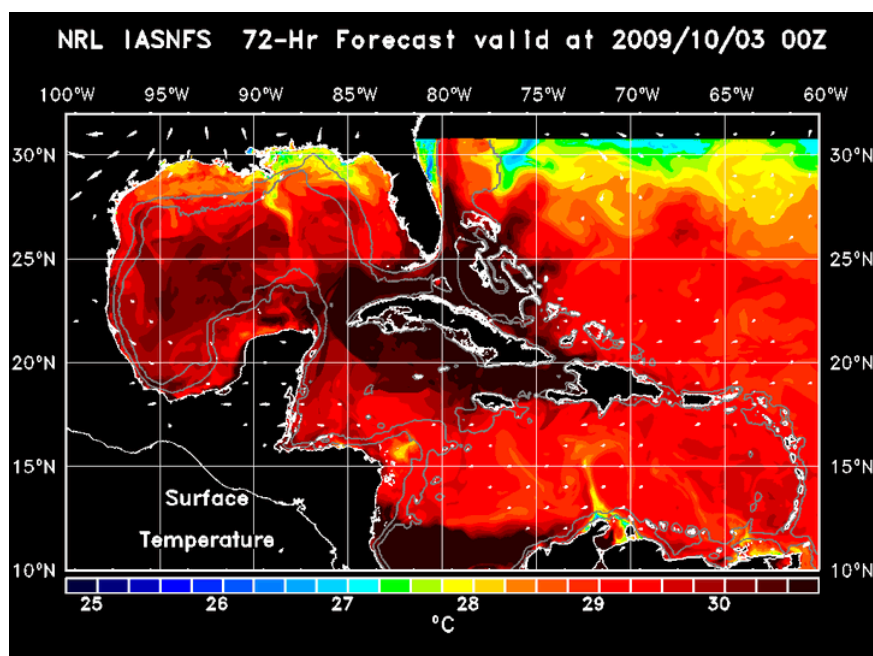


*Figure 5. FNMOC COAMPS West Pacific regional weather forecast model 48-hour forecast for 2009/10/02 00Z. Colors show sea level air pressure with wind speed vector superimposed.*





*Figure 6. The NRL EASNFS nowcast of ocean temperature at 25 m depth for 2009/08/16 00Z to support ONR QPE field experiment. The morning locations are indicated by “+”.*



*Figure 7. The NRL IASNFS 72-hour forecast of sea surface temperature for 2009/10/03 00Z. The wind stresses from FNMOC NOGAPS are superimposed.*

## **RESULTS**

The NRL EASNFS was developed to support ONR NLIWI modeling effort in the previous years. The model prediction has been used for the open boundary condition for the high resolution models to study the non-linear internal waves at South China Sea, e.g., Chao et al (2007) and Shaw et al. (2009).

For the FY09, we attended 2 ONR sponsored workshops at Seattle and Honolulu to discuss outline of research and experiment plan, examined the work done for TSC08 and to forge cooperations with other Typhoon DRI PIs. Attended the ONR PO Review at Chicago to report the progress.

Starting from June 1, 2009 we conducted real-time ocean prediction experiments using EASNFS and IASNFS for both West Pacific and Atlantic regions. Daily ocean predictions as well as satellite remote sensing data and weather forecasts are provided to Typhoon DRI PIs. All the data are archived to support the planned future field experiment.

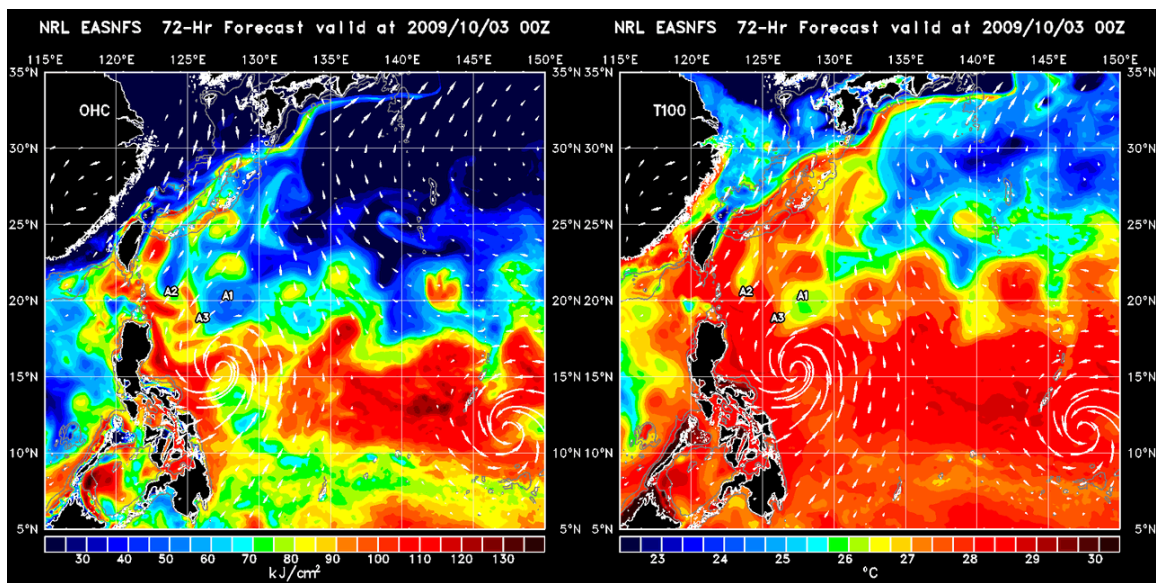
A high-resolution ocean nowcast/forecast covering the region of ITOP moorings at West Pacific Ocean has been developed and made a transition to Typhoon PI Chao at University of Maryland. Provided guidance to Chao's graduated student to operate the system. Performed case studies for the 2007 typhoon season.

## **IMPACT/APPLICATIONS**

The real-time EASNFS ocean predictions were applied to the mission planning for the TCS-08 field experiment at the Western North Pacific. It has been shown that it is very useful for field work mission planning. The same predictions should provide valuable inputs for coming 2010 Typhoon DRI field experiment and in a planned 2008 future field experiment. The EASNFS prediction has been used to support ONR QPE field experiment at northeastern of Taiwan during August, 2008. With a daily ocean forecast for the region the QPE PIs were able to track interesting oceanic features on the cruise.

The EASNFS and IASNFS products were provided to other Typhoon DRI PIs so that they can initialize their ocean/wave/atmosphere models and use the products for boundary conditions. EASNFS 3D temperature prediction was applied by Typhoon DRI PI Jim Price (2009) to study the difference in use of the Ocean Heat Content or 100-meter average temperature as a predictor for typhoon intensity prediction (Figure 8).





**Figure 8.** *The NRL EASNFS 72-hour forecast of 100-m temperature average (T100) vs the OHC. Study by Jim Price (2009) suggests that T100 is a better predictor for the typhoon intensity.*

## RELATED PROJECTS

NRL 6.2 Coupled Ocean-Wave Prediction System (PI/POC – Rick Allard) – PI serves as a convoy between two research groups.

ONR QPE – Provides Ocean prediction to support field experiment and applies field observations for collaborated researches.

ITOP (Taiwanese counterpart of ONR Typhoon DRI) – Exchanges data and conducts collaborated researches with ITOP PIs.

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## **PUBLICATIONS**

[p.1]- Ko, D.S., S.-Y. Chao, P. Huang, and S.F. Lin, Anomalous upwelling in Nan Wan: July 2008, *Terr. Atmos. Ocean. Sci.*, 2009. [in press]

[p.2]- Ko, D.S., S.-Y. Chao, Y. T. Chang, and S. F. Lin, A real-time ocean nowcast/ forecast system for typhoon-ocean interaction study, Ocean Science Meeting, 2010.  
[submitted]